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by

Matthew J. Evenson

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ABSTRACT

Abundance of burbot *Lota lota* 400 millimeters and larger was estimated for one 40 kilometer section of the upper Tanana River (Northway section) and for one 24 kilometer section of the lower Chena River (Chena section) using mark-recapture techniques. All sampling was conducted between June 12 and September 28, 1990. Abundance was 4,803 (standard error = 848) for the Northway section and 1,966 (standard error = 338) for the Chena section. Indices of abundance (catch-per-unit of effort statistics) for large burbot (450 millimeters and larger) were calculated for each of five sampling events conducted in the Chena section and ranged from 0.07 (standard error = 0.02) for a sampling event conducted in June to 1.21 (standard error = 0.09) for a sampling event conducted in September. Indices of abundance were also calculated for two sampling events conducted in the Northway section and for one sampling event conducted in a 32 kilometer section of the Tanana River near Fairbanks (Fairbanks section). Indices of abundance were 0.60 (standard error = 0.04), 0.93 (standard error = 0.05), and 1.11 (standard error = 0.12) for these sections, respectively. Estimates of mean total lengths for large burbot were 552 millimeters (standard error = 4) for the Chena section, 617 millimeters (standard error = 5) for the Northway section, and 553 millimeters (standard error = 8) for the Fairbanks section.

KEY WORDS: burbot, *Lota lota*, abundance, hoop traps, Tanana River, Chena River, mean length, Relative Stock Density, catch-per-unit of effort, movement.

INTRODUCTION

Research concerning burbot *Lota lota* stocks in flowing waters of the Tanana River system has been ongoing since 1983. The objectives of this research program have been to determine biological characteristics such as size, age, and density distributions, identify migratory behavior, examine spawning characteristics, monitor harvests, and determine characteristics of the sport fishery. These research investigations have been important prerequisites for more specific studies concerning system-wide population parameters, such as abundance, survival, and recruitment, needed to attain the management goal of ensuring sustainable yield of these stocks.

Because of the immenseness of the Tanana River system, measurement of population parameters is complex and difficult to obtain in a cost effective manner. The primary approach used to date to assess the stock status of burbot in rivers has been to index abundance through catch-per-unit of effort (CPUE) data and to estimate length compositions in various sample sections throughout the river system using a standardized design. Since 1983, the sampling design has been improved and refined to the point that many precise estimates of length compositions and CPUE have been obtained. However, the factors which may influence these estimates in a given river section, such as time of sampling, migratory behavior, catchability, river velocity, and other limnological considerations are unclear.

Abundance estimates for burbot have been obtained in a 16 km section of the Tanana River near Fairbanks in 1986 and 1987 (Hallberg et al. 1987; Evenson 1988) and in a 16 km section of the Tanana River near Healy Lake outlet in 1987 (Evenson 1988). This study provides abundance estimates for burbot in a 40 km section in the upper Tanana River near Northway, and in a 24 km section of the lower Chena River. Abundance estimates provide a measure of stock status which is useful for management purposes, however the attainment of an abundance estimate is more costly and time consuming than investigations required to attain a CPUE estimate. Because abundance estimates are more desirable than CPUE estimates, a better understanding of the relationship between CPUE and abundance is sought. Preliminary data indicate that CPUE estimates do not correlate well with abundance estimates. For example, relative abundance based on CPUE in the Healy Lake area was eight times greater than in the Fairbanks area, while actual abundance in the Healy Lake area was only about four times as great.

In order to better manage populations of burbot in rivers, the goal of this study is to relate CPUE to abundance. The objectives of this investigation in 1990 were to estimate:

1. the abundance of all burbot 300 mm total length (TL) and longer in one 40 km section of the Tanana River and one 25 km section of the Chena River; and,

2. the mean length of all burbot captured in these two sections.

In addition, estimates of mean CPUE were obtained for the above two river sections as well as for a 32 km section of the Tanana River near Fairbanks.

Length compositions of all burbot captured in these three river sections were further examined by estimating proportions of Gabelhouse (Gabelhouse 1984) length categories.

STUDY AREA

Sampling was conducted in two sections of the Tanana River ("Northway" and "Fairbanks" sections) and in one section of the Chena River ("Chena" section; Figure 1). Estimates of abundance were calculated for the Northway and Chena sections, while the Fairbanks section was sampled for an index of abundance. Historic catch data from these three sections are shown in Appendices A1 and A2.

Northway Section

This section encompasses the headwaters region of the Tanana River in close proximity to Northway. Sampling in this section was conducted beginning at river kilometer 888 in the Tanana River[1] and extended 16 km upstream to the confluence of the Chisana and Nabesna rivers. The lower 8 km of the Nabesna River, as well as the lower 16 km of the Chisana River were also sampled. A total of 40 km encompassing the three rivers were sampled. The study section was split into three divisions in order to analyze movement behavior. The boundaries for the first division began at river kilometer 888 of the Tanana River and extended upstream to river kilometer 900. Boundaries for the second division included the remaining 4 km of the Tanana River, all 8 km of the lower Nabesna River, and the lower 1 km of the Chisana River. The third division began at river kilometer 2 of the Chisana River and extended upstream to river kilometer 16.

Chena Section

This section encompassed that portion of the lower Chena River in close proximity to Fairbanks. The section was 24 km in length. The boundaries of the section began at the confluence of the Chena and Tanana rivers (river kilometer 0) and extended upstream 24 kilometers. For analysis of movements, this section was split into three divisions. Each division was 8 km in length, with division one being the most downstream, and division three being the most upstream.

Fairbanks Section

This section encompassed that portion of the Tanana River in close proximity to Fairbanks. The section was 32 km in length. The boundaries of the section began at river kilometer 344, and extended upstream to river kilometer 376. The confluence of the Chena River was located in the center of the section.

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[1] All river area locations cited throughout this report were measured in kilometers upstream from the river's mouth.

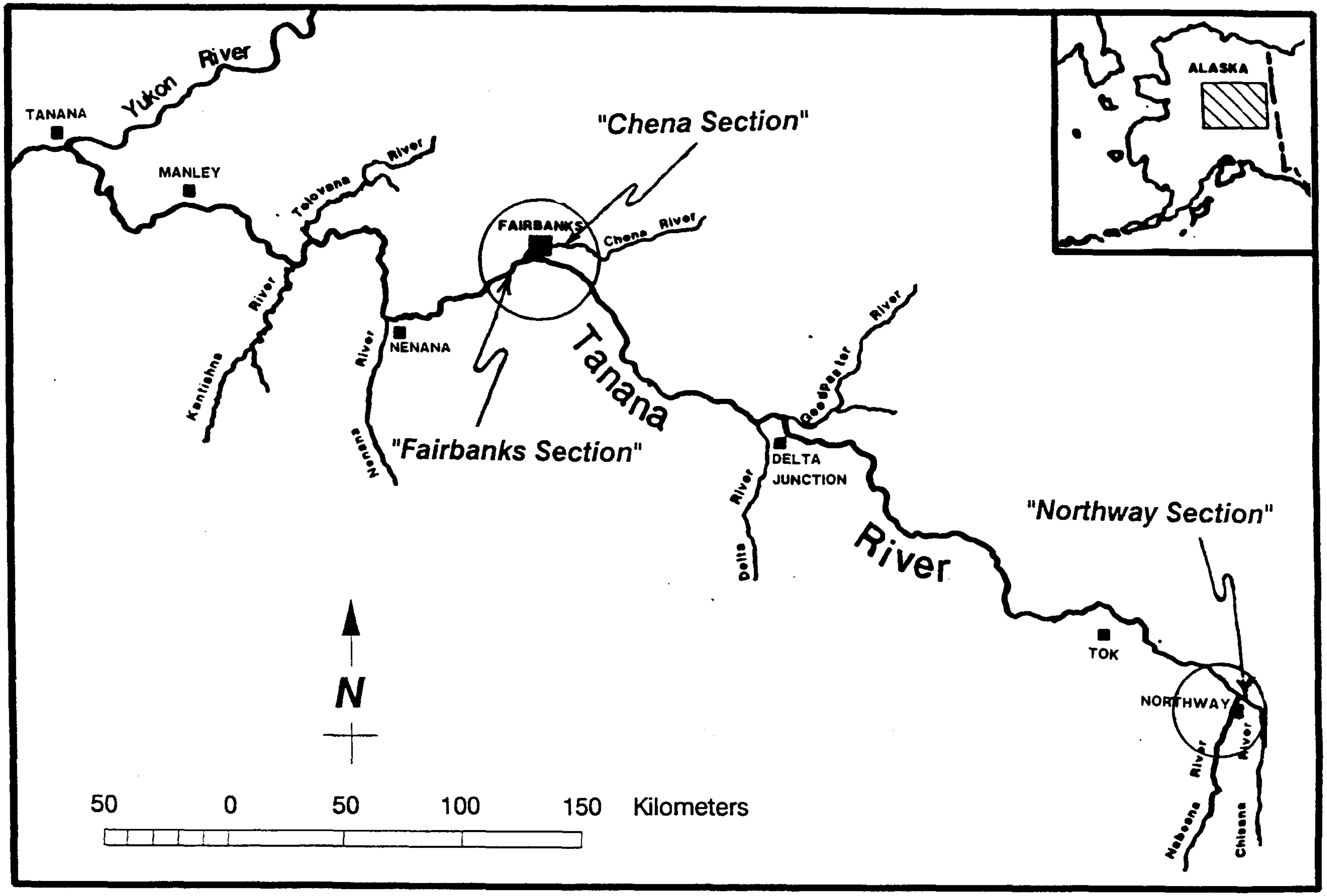

Figure 1. Map of the Tanana River drainage showing sampling locations during 1990.

METHODS

Gear Description

Burbot were captured in hoop traps 3.05 m long with seven 6.35 mm steel hoops (Figure 2). Hoop diameters taper from 0.61 m at the entrance to 0.46 m at the cod end. Each trap has a double throat (tied to the second and fourth hoops) which narrows to an opening 10 cm in diameter. All netting is knotted nylon woven into 25 mm bar mesh, bound with No. 15 cotton twine, and treated with an asphaltic compound. Each trap is kept stretched with two sections of 19 mm PVC pipe attached by snap clips to the end hoops.

Hoop traps were baited with cut Pacific herring *Clupea harengus* placed in perforated plastic containers. One end of a five to 10 m section of polypropylene rope was tied to the cod end of each trap, while the other end was tied off to shore. The traps then fished on the river bottom near shore with the opening facing downstream. An outboard-powered riverboat was used to set, move, and retrieve the traps.

Study Design

The general, sampling protocol was similar for all three river sections except the dates of sampling, duration and number of sampling events, and amount of effort were variable for each (Table 1). In all sections, traps were set along both shores at near equal intervals beginning at the most downstream end of the section and progressing to the most upstream end of the section. All traps were fished for approximately 24 hours, rebaited, and then moved to a slightly upstream area. All trap locations were marked on 1:63,360 USGS maps and recorded to the nearest kilometer. All burbot captured were measured for total length (TL) to the nearest millimeter, and tagged using individually numbered Floy internal anchor tags. All fish in the Chena and Northway sections were given a unique fin-clip corresponding to the sampling event (marking or recapture) and the division within the section (upper, middle, or lower). All fish were released at the capture site.

Abundance Estimation

The methodology developed to estimate abundance of burbot in rivers of interior Alaska is based on the Petersen method (described in Seber 1982), but is often modified due to the movement behavior of burbot between sampling events, and the inherent size selective bias of the hoop trap gear. Segregation of the study area into three divisions is used to quantify movements, and long study areas are chosen to help minimize emigration of fish during the experiment. Size selectivity can usually be identified (using statistical procedures described below) and corrected for, or can be inferred from previous studies (Evenson 1988; Parker et al. 1987, 1988; Bernard et al. 1991).

In the Northway section, a single sampling event constituted the marking sample, and a single sampling event constituted the recapture sample. Each sampling event lasted eight days, and there was a 13 day hiatus between the

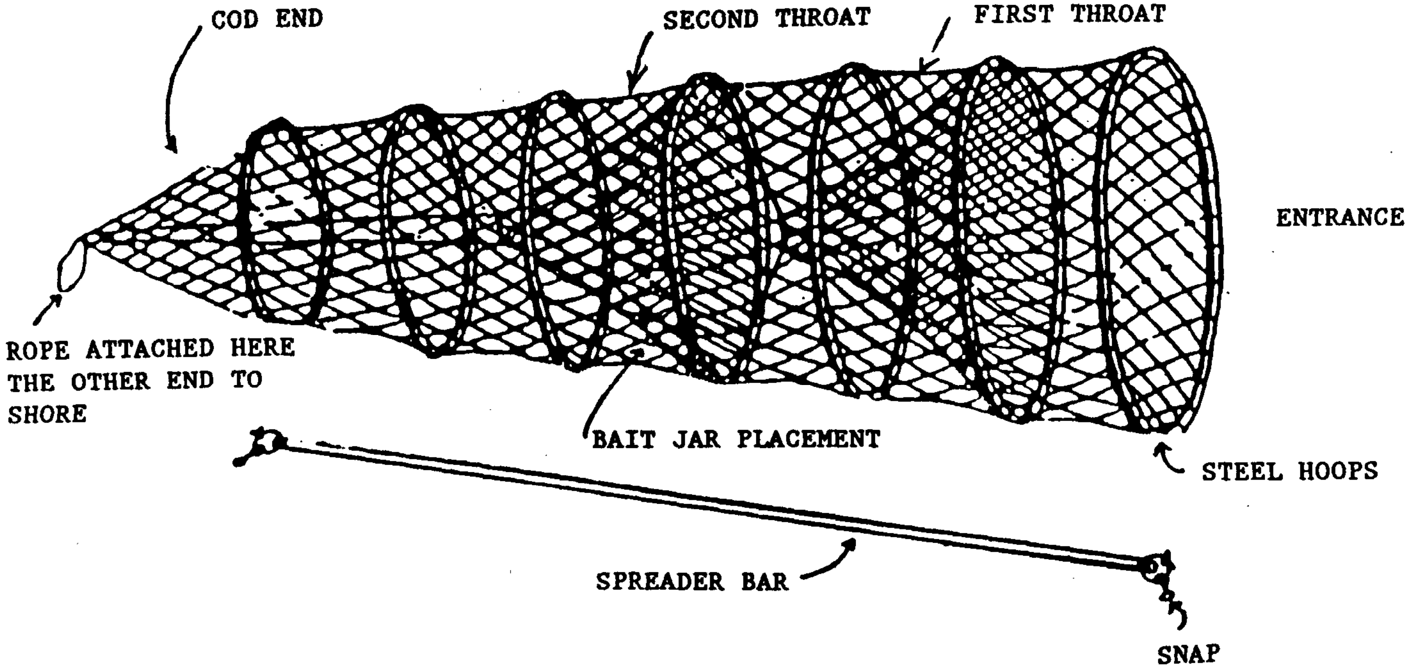

Figure 2. Diagram of hoop trap gear used to capture burbot in the Chena and Tanana rivers during 1990.

Table 1. Summary of sampling events conducted in the Tanana and Chena rivers during 1990.

Sampling Event	Dates of Sampling	Length of Sample Section (km)	Number of Traps Fished	Trap Density (No. Traps per Day per river km)
Tanana River				
Northway Section:				
1[a]	6/21 - 6/28	40	458	1.4
2[b]	7/10 - 7/18	40	393	1.1
Fairbanks Section:				
1	8/14 - 8/16	32	90	0.9
Chena River				
Chena Section:				
1	6/12 - 6/15	24	232	2.4
2[a]	8/20 - 8/23	24	204	2.1
3[a]	8/28 - 8/31	24	203	2.1
4[b]	9/06 - 9/07	24	73	1.5
5[b]	9/27 - 9/28	24	80	1.7

[a] Marking sample for abundance estimate.
[b] Recapture sample for abundance estimate.

two events. Approximately equal effort (number of traps set) was expended during each event (Table 1).

In the Chena section, two separate sampling events constituted the marking sample, and two separate sampling events constituted the recapture sample. The first two sampling events each lasted four days, or a total of eight days for the marking sample. The last two sampling events each lasted two days, or a total of four days for the recapture sample. The two marking events were conducted over a span of 11 days, while the two recapture events were conducted over a span of 22 days. There was a six day hiatus separating the marking and recapture samples. A total of 407 net-nights of effort were expended during the marking sample, while 153 net-nights were expended during the recapture sample (Table 1).

The assumptions for an unbiased estimate of abundance using mark-recapture methods (Seber 1982) in this experiment are:

1) the population is closed (no change in the number of burbot in the population during the estimation experiment);

2) all burbot have the same probability of capture during the first sample <u>or</u> in the second sample <u>or</u> marked and unmarked burbot mix randomly between the first and second samples;

3) marking of burbot does not affect their probability of capture in the second sample; and,

4) burbot do not lose their mark between sampling events.

Assumption 1 was not tested directly, but migration of fish out of the river section was inferred from analysis of movements of fish within and among the three study divisions. A recapture matrix was created in which the rows corresponded to the capture location, and the columns corresponded to the recapture location. If a high proportion of fish were noted as moving a distance greater than the length of the individual study division, then the assumption that the population is closed to immigration and emigration was considered false. Other factors possibly contributing to the failure of assumption 1 (mortality and growth recruitment) were assumed to be negligible. The short duration of the experiments should have prevented appreciable mortality and growth from occurring. In practice, this test is performed after examining (and adjusting if necessary) assumption 2 as shown below.

The three "or" conditions of assumption 2 are multifaceted, and include space, time, and size parameters. Equal probability of capture during each sampling event by size was tested with two Kolmogorov-Smirnov two-sample statistical tests. The first test compared the length frequency distributions of recaptured burbot with those captured during the marking sample. The second test compared the length frequency distributions of burbot captured during the marking sample with those captured in the recapture sample. The results of these two tests determined the methodology used to alleviate bias in abundance estimation (see Appendix B1).

The possibly size-stratified data from the recapture sample were then arranged in a 3 x 2 contingency table. The two columns corresponded to the number of burbot recaptured and the number of burbot not recaptured. The three rows corresponded to the three divisions within a sample section. Null hypotheses of this test are either marked fish mix completely with unmarked fish <u>or</u> all burbot in the marking sample have an equal probability of capture in all divisions. If the test is not significant ($\alpha = 0.05$), it is not known whether one or both of the two hypotheses are valid, but at least one is, which satisfies the conditions for assumption 2. If the results of this test were significant, then the recapture matrix (described above) was inspected. If all the off-diagonal elements of this matrix were zero (no movement), then a <u>minimum</u> Petersen estimate for all divisions was calculated by first estimating abundance for each division individually, and then adding all three to obtain the total estimate for the section. If the off-diagonal estimates were not zero, then only partial mixing occurred, and a Darroch estimator (Darroch 1961) would be used to estimate abundance.

Marking and handling burbot should not affect their probability of recapture (assumption 3). The hiatus in these experiments (13 and six days for the Northway and Chena sections, respectively) should have been ample time to reverse any behavioral changes ("trap happiness", "trap shyness", or physiological stress) which may have been associated with the experience of being captured.

Because double marking was employed, no tag loss should have occurred (assumption 4) unless fish without tags were not inspected for fin clips. To minimize the possibility of this occurring, a unique fin-clip was also given to all fish collected during the recapture sample. This helped to remind sampling crews to inspect for previous clips.

If these assumptions were all met, and if inter-divisional movement was observed in low proportions, then the modified Petersen estimator of Bailey (1951, 1952) was used to estimate abundance:

$$\hat{N} = \frac{M\,(C + 1)}{(R + 1)} \qquad (1)$$

$$V(\hat{N}) = \frac{M^2\,(C + 1)\,(C - R)}{(R + 1)^2(R + 2)} \qquad (2)$$

where: M = the number of burbot marked and released alive during the first sample;

C = the number of burbot examined for marks during the second sample;

R = the number of burbot with marks (from the first sample) collected during the second sample; and,

$\hat{N}$ = the estimated abundance of burbot during the first sample.

Alternatively, if significant inter-divisional movement of fish in the study section was observed between the marking (first event) and recapture (second event) samples, a modified Petersen estimator (Bernard Pers. Comm.[2]; Evenson 1988) was used to compensate for the movement of marked burbot out of the study section. The additional assumptions necessary for accurate use of this estimator are:

6) no burbot tagged in the midstream area migrate out of the study section; and,

7) a single process causes upstream movement, and a single process causes downstream movement.

The modified Petersen estimator that accounts for movements of tagged fish is:

$$\hat{N} = \frac{\{ M_1(1-\hat{\Theta}_d) + M_2 + M_3(1-\hat{\Theta}_u) \} \{C + 1\}}{R_{..} + 1} \quad (3)$$

where:

M_x = the number of burbot marked in the first event in section x (x = 1, 2, and 3 for the downstream, midstream, and upstream areas, respectively);

$R_{..}$ = the number of burbot recaptured during the second sample;

Θ_z = the probability that a burbot will move out of an area in the z direction (<u>u</u>pstream or <u>d</u>ownstream);

C = the catch during the second sample; and,

$\hat{N}$ = the abundance of burbot in <u>all</u> areas at the start of the second sample.

The probabilities of movements are estimated by:

$$\hat{\Theta}_d = \frac{M_2(R_{32} + R_{21})}{R_{2.}(M_3 + M_2)}; \quad (4)$$

$$\hat{\Theta}_u = \frac{M_2(R_{12} + R_{23})}{R_{2.}(M_1 + M_2)} \quad (5)$$

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[2] Bernard, David. Personal Communication. ADFG, Sport Fish Division, 333 Raspberry Rd., Anchorage, AK 99518.

where:

R_{xy} = the number of burbot that were marked in area x during the first sample and were recaptured in area y during the second sample; and,

$R_{2.}$ = the number of burbot that were marked in the midstream area during the first sample and were recaptured during the second sample.

Variances of these estimates (equations 3, 4, and 5) were calculated by bootstrapping (Efron 1982). First, capture history of each fish was recorded by division. A capture was denoted with the division (1 for downstream, 2 for midstream, and 3 for upstream). If the fish was not seen, this was denoted by a zero. The total number of capture histories was the sum of fish marked in the first sample plus the total number of fish examined in the second sample minus two times the number of fish seen in both samples (recaptures). These capture histories were then resampled with replacement 500 times by computer. Each replication of the estimation experiment involved sampling of "the total number of capture histories" and then calculating an abundance estimate (and probabilities of movement for the modified estimator). After 500 replications the mean and standard variance for a mean (Snedecor and Cochran 1980) were calculated for all replicates.

Catch-per-Unit of Effort

Mean CPUE (defined as burbot per net-night) for each river section and its associated variance were calculated from the number of burbot caught per net-night for all traps set during each sampling period based upon the following equations from Wolter (1984):

$$\overline{CPUE_c} = \bar{X}_c + \frac{\sum_{h=1}^{t} X_{ch};}{t} \qquad (6)$$

$$V[\overline{CPUE_c}] = \frac{\sum_{h=2}^{t} [X_{ch} - X_{ch-1}]^2}{2t[t-1]} \qquad (7)$$

where:

X_{ch} = catch of burbot of size class c in hoop trap h;

t = the total number of hoop traps in a river section;

h = the set number such that h = 1 to t in order with h = 1 the most downstream set and h = t the most upstream;

$\bar{X}_c$ = mean catch; and,

$\overline{CPUE_c}$ = mean CPUE of burbot of size class c.

Typically, full recruitment to the hoop trap gear used in this study begins at 450 mm TL (Evenson 1988; Bernard et al. 1991). In some cases however, large burbot (greater than 800 mm TL) are caught less frequently (Bernard et al. 1991). Because no mark-recapture experiment was conducted in the Fairbanks section, size selectivity could not be tested. Therefore, based on the findings of the above studies, mean CPUE was estimated for three size classes (less than 450 mm TL, 450 to 800 mm TL, and greater than 800 mm TL). The number of size classes for which mean CPUE was estimated in the Northway and Chena sections was determined by statistical procedures as described above under the abundance estimation section.

More than one sampling event was conducted during the mark-recapture estimates for the Chena and Northway sections. If both events were considered unbiased (for length), an estimate of mean CPUE for all events in each of these sections was:

$$\overline{CPUE} = \sum_{p=1}^{d} W_p \overline{CPUE_p}; \qquad (8)$$

$$V[\overline{CPUE}] = \sum_{p=1}^{d} W_p^2 V[\overline{CPUE_p}] \qquad (9)$$

where:

$W_p = h_p/h$ = the number of hoop traps set in sampling event p divided by the total number of hoop traps set in all d sampling events.

Length Composition

For the same reasons described above concerning selectivity of the gear, estimates of mean length were stratified by length categories. For all three river sections, mean length for burbot in each of three length categories (less than 450 mm, 450 to 800 mm, and greater than 800 mm TL) was calculated as:

$$\bar{l}_c = \sum_{b=1}^{n} \frac{l_{cb}}{n_c}; \qquad (10)$$

$$V[\bar{l}_c] = \sum_{b=1}^{n} \frac{(l_{cb} - \bar{l}_c)^2}{n_c(n_c-1)} \qquad (11)$$

where:

l_{cb} = length of burbot b in length category c; and,

n_c = number of samples in length category c.

Unless determined otherwise, only the estimate of mean length for burbot 450 to 800 mm TL is considered unbiased. In the Northway and Chena sections for which more than one sampling event occurred, statistical testing (described in the abundance estimation section) determined which sampling events were unbiased. If more than one event was considered unbiased, then length data were combined and mean lengths were calculated as:

$$\bar{l}_t = \sum_{p=1}^{d} W_p \bar{l}_c; \tag{12}$$

$$V[\bar{l}_t] = \sum_{p=1}^{d} W_p^2 V[\bar{l}_c] \tag{13}$$

where:

$W_p = n_p / \sum_{a=1}^{k} n_c$ = number of samples in event p divided by the total number of samples in all d events.

Minimum length categories for Relative Stock Density were defined after review of Gabelhouse (1984). Categories were modified to accommodate the selectivity of the hoop trap gear. The "stock" category was defined as 300 to 449 mm TL; "quality" was 450 to 599 mm TL; "preferred" was 600 to 699 mm TL; "memorable" was 700 to 799 mm TL; and, "trophy" was 800 mm TL and larger. Typically, size selectivity occurs with the stock category and occasionally with the trophy category. Thus, only proportions for categories containing fully recruited burbot were calculated. Relative Stock Densities were calculated for all sections as:

$$\hat{F}_{cp} = n_{cp} / m_p; \tag{14}$$

$$V[\hat{F}_{cp}] = \frac{\hat{F}_{cp}(1-\hat{F}_{cp})}{(m_p-1)}; \tag{15}$$

where:

n_{cp} = the number of fish in length category c from sample event p; and,

m_t = the total number of fish in all length categories from sample event p.

In those sections for which more than one sampling event was considered unbiased, length data were combined and Relative Stock Densities were calculated for all d sampling events as:

$$\hat{F}_c = \frac{\sum_{p=1}^{d} \sum_{c=1}^{m} n_{cp}}{\sum_{p=1}^{d} m_p}; \qquad (16)$$

$$V[\hat{F}_c] = \frac{\hat{F}_c(1 - \hat{F}_c)}{\sum_{p=1}^{d} m_p} \qquad (17)$$

where:

$\hat{F}_c$ = Relative Stock Density of length category c for all d events.

RESULTS

Abundance Estimate: Northway Section

A total of 374 burbot larger than 300 mm TL were caught and marked during the first sample, and a total of 454 were caught and examined for marks during the second sample. Of those collected during the second sample, 23 had marks from the first sample (recaptures). Five immediate mortalities were recorded during both events for an overall mortality rate of 0.6%. No tags were lost during the sampling period.

Test for Size Selectivity:

Kolmogorov-Smirnov two sample tests comparing a) Cumulative distribution functions (CDF) of all fish collected during the first sample and all recaptured fish collected during the second sample; and, b) CDF of all fish collected during the first sample and all fish collected during the second sample indicated that there was size-selectivity during the first sample, but not during the second (*test a*, $P > 0.99$; *test b*, $P < 0.01$; Figure 3). The protocol described in Appendix B1 calls for one unstratified estimate of abundance, using only data from the second sample to estimate length compositions. However, because only one fish was recaptured with a length less than 400 mm TL, and because full recruitment to hoop traps generally begins somewhere between 400 and 500 mm TL, a single estimate of abundance for all fish 400 mm TL and larger was calculated. Only length data from the second sample (400 mm TL and larger) were used to estimate length compositions and CPUE.

Test for Equal Probability of Capture and Random Mixing:

Contingency table analysis indicated that marked-to-unmarked ratios were significantly different among all divisions ($\chi^2 = 6.22$, $df = 2$, $P < 0.05$).

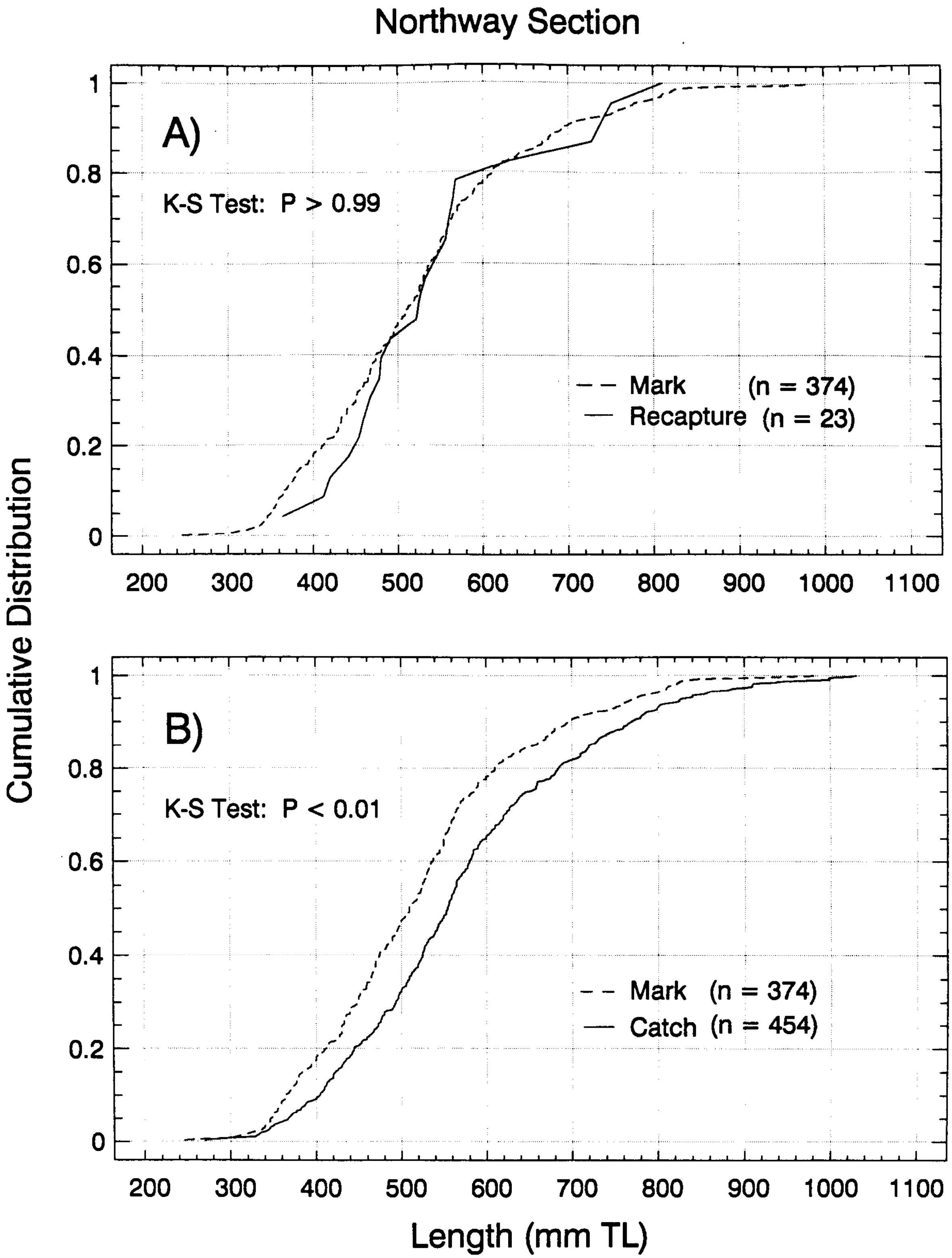

Figure 3. Cumulative length frequency distributions of burbot captured in the Northway section of the upper Tanana River, comparing lengths of all burbot captured during the marking sample to: A) lengths of all recaptured burbot; and, B) lengths of all burbot captured during the recapture sample.

Examination of recapture rates indicated that this difference was due to a relatively low probability of recapture in the upstream section (Table 2).

Test for Significant Movement:

Movement of marked fish among divisions occurred between sampling events (Table 3). Seven of the 22 recaptured fish (400 mm TL and larger) moved out of the division in which they were tagged (four upstream, three downstream). No recaptured fish were documented as moving more than one division upstream or downstream. The greatest movement of any recaptured fish was 16 km downstream, while the mean distance moved for all recaptured fish was five km (Figure 4).

Estimate of Abundance:

The results of the above tests indicated that only partial mixing between sampling events occurred, and a Darroch estimator (Darroch 1961) was appropriate. However, due to the low rates of recapture in each division, resampling techniques (Efron 1982) produced an unacceptable number of negative values when calculating capture probabilities in each division. Thus, the Darroch model was unable to produce a reliable estimate of abundance. The violation of the three "or" assumptions was most likely due to burbot in the upstream division migrating upstream out of the study section. In order to compensate for the bias caused by this emigration, the modified Petersen model of Bernard (Evenson 1988) was used to estimate abundance for all burbot 400 mm TL and longer.

The estimated abundance of burbot 400 mm TL and longer in this 40 km river section using resampling techniques was 4,803 (*SE* = 848; Table 4), or a density of 120 burbot per kilometer. This compares to a point estimate of 4,656, giving a statistical bias of 149 (3%; Figure 5). This estimate was 12% lower than the Bailey modification (Bailey 1951, 1952) which estimated abundance to be 5,436 (*SE* = 1,037; Table 4). Probabilities of movement were 26% (*SE* = 11%) for upstream and 12% (*SE* = 11%) for downstream. This further supported the hypothesis that there was significant movement out of the study section most likely in the upstream division.

<u>Abundance Estimate: Chena Section</u>

A total of 397 burbot larger than 300 mm TL were caught and marked during the first sample, and a total of 186 were caught and examined for marks during the second sample. Of those collected during the second sample, 27 had marks from the first sample (recaptures). Three immediate mortalities were recorded during all events for an overall mortality rate of 0.5%. No tags were lost during the sampling period.

Test for Size Selectivity:

Kolmogorov-Smirnov two sample tests comparing a) CDF of all fish collected during the first sample and all recaptured fish collected during the second sample; and, b) CDF of all fish collected during the first sample and all fish collected during the second sample indicated that there was size-selectivity

Table 2. Number of marked burbot (400 mm TL and larger) recovered in divisions of the Northway section of the upper Tanana River during 1990.

	River Division			
	Lower	Middle	Upper	Total
Recovered	6	11	5	22
Not Recovered	41	106	141	288
Total Marked	47	117	146	310
Recovery Rate	13%	9%	3%	7%

Table 3. Inter-division movements of recaptured burbot in the Northway section of the Tanana River during 1990.

Division Tagged	Division Recaptured		
	Lower	Middle	Upper
Lower	4	2	0
Middle	3	6	2
Upper	0	0	5

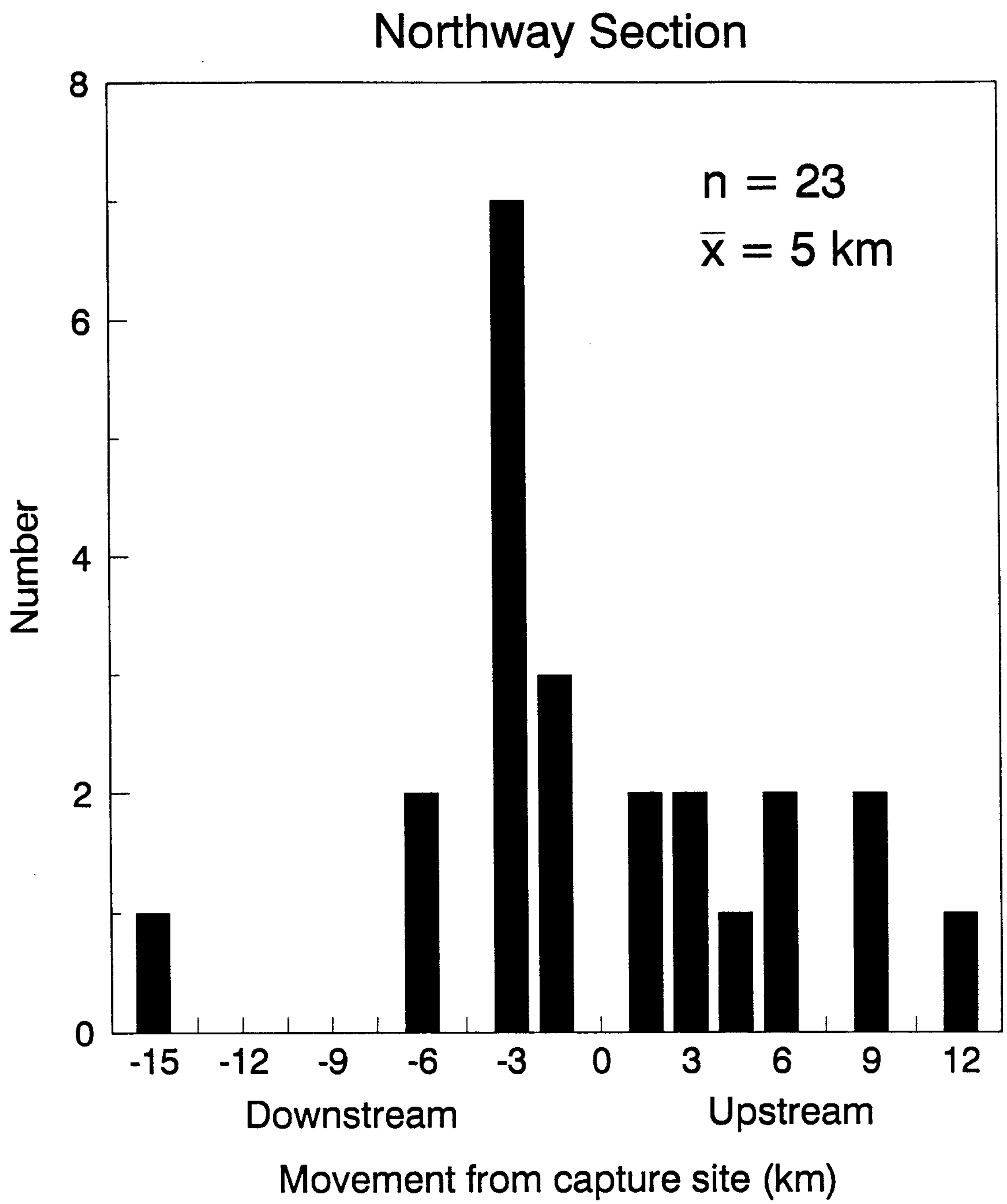

Figure 4. Movements of all recaptured burbot caught during the mark-recapture experiment in the Northway section of the upper Tanana River during 1990.

Table 4. Abundance estimate of large burbot (400 mm TL and larger) in the Northway section of the upper Tanana River during 1990.

Parameter	Calculated or Known Quantity	Bootstrap Estimate
M_1	47	47
M_2	117	117
M_3	146	146
C	401	401
$R_{..}$	22	22
R_{12}	2	2
R_{23}	2	2
R_2	11	11
R_{21}	3	3
R_{32}	0	0
Θ_u	0.26	0.26
SE	Unknown	0.11
Θ_d	0.12	0.12
SE	Unknown	0.11
$\hat{N}$ (Evenson 1988)	4,656	4,803
SE	Unknown	848
$\hat{N}$ (Bailey 1951,1952)	5,436	
SE	1,037	

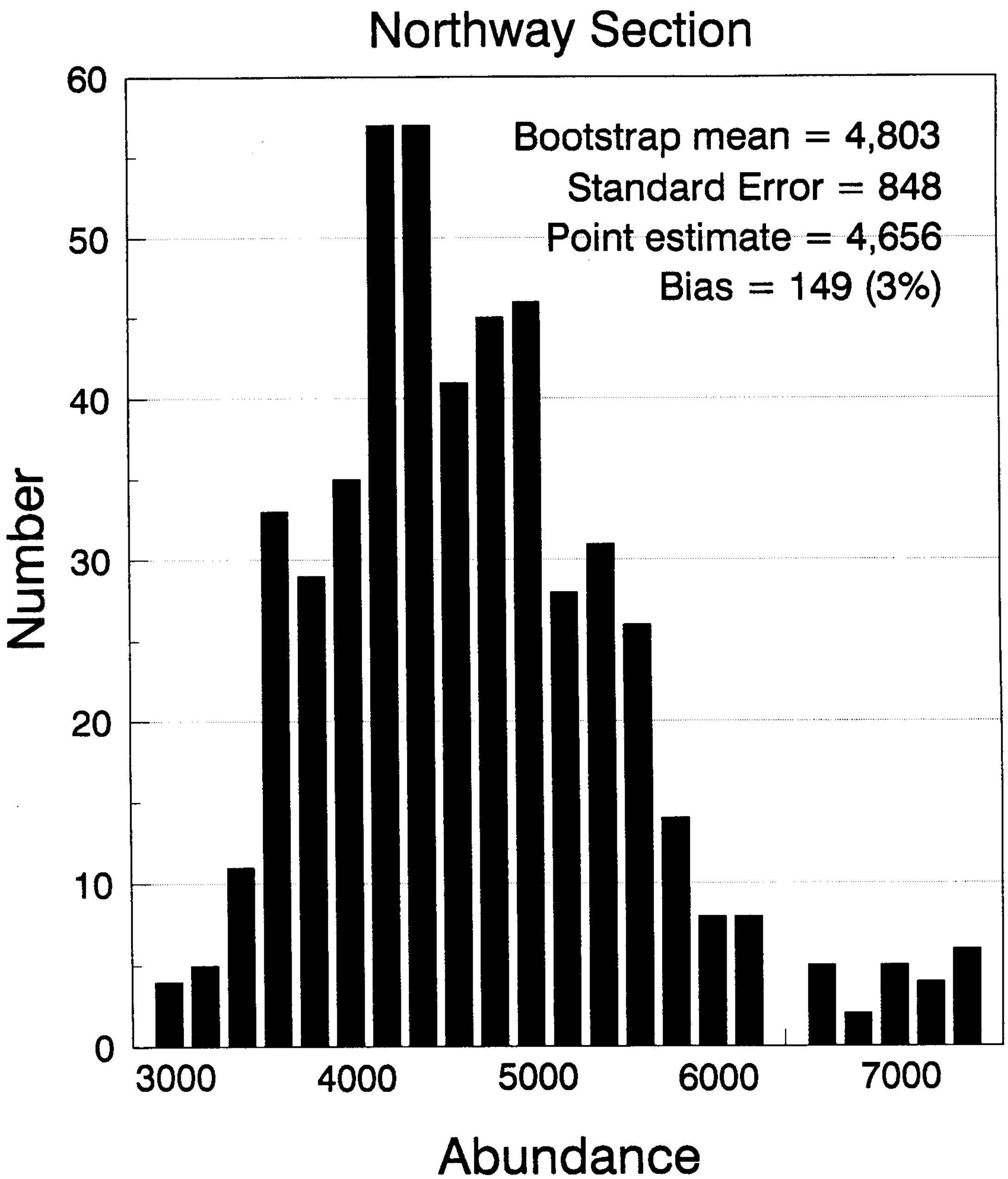

Figure 5. Distributions of 500 bootstrap estimates of abundance and statistical bias from the mark-recapture experiment in the Northway section of the upper Tanana River during 1990.

during the both samples (*test a)* $P < 0.005$; *test b)* $P < 0.05$). Although test b was statistically significant, the null hypothesis was not rejected based on the similarities of the two plotted distributions and the large sample sizes of both samples (Figure 6). From Appendix B1, stratification by size was required to alleviate bias. A series of Chi-Square tests were conducted to determine the optimum stratification scheme. These tests indicated that there should be two strata with the break at 400 mm TL (Table 5). Because only one recaptured fish was captured in the small length stratum, abundance was estimated for the large stratum only. Length data from both samples were pooled to improve precision of length composition and CPUE estimates.

Test for Equal Probability of Capture and Random Mixing:

Contingency table analysis indicated that marked-to-unmarked ratios were not significantly different among divisions ($\chi^2 = 2.92$, $df = 2$, $P > 0.10$). Examination of recapture rates indicated that probabilities of recapture were similar for all divisions (Table 6).

Test for Significant Movement:

Inter-division movement of marked fish between sampling events occurred (Table 7). However, only three of the 26 recaptured fish (400 mm TL and larger) moved out of the division in which they were tagged (two upstream, one downstream). No recaptured fish were documented as moving more than one division upstream or downstream. The greatest movement of any recaptured fish was 13 km upstream, while the mean distance moved for all recaptured fish was 1 km (Figure 7).

Estimate of Abundance:

The above tests indicated that Bailey's (1951, 1952) model was appropriate for estimating abundance. To further investigate whether significant inter-division movement occurred, an estimate using Bernard's model (Evenson 1988) was calculated and compared to the former estimate. Probabilities of movement were 13% (*SE* = 11%) for upstream and 5% (*SE* = 4%) for downstream. Estimated abundance of burbot 400 mm TL and longer was 2,072 (*SE* = 359) using Bailey's model, and was 1,964 (*SE* = 338) using Bernard's model (Table 8).

<u>Catch-per-Unit of Effort</u>

Catch-per-unit of effort statistics were calculated for all sampling events in all sections.

Northway Section:

An unbiased estimate of mean CPUE was obtained for all burbot 400 mm and larger, and considered only catches from the second sample. Mean CPUE was estimated to be 1.06 (*SE* = 0.06). In the past, CPUE has been estimated for all burbot 450 mm TL and larger. For comparative purposes, and because catches from this length category are also unbiased, an estimate of CPUE for burbot 450 mm TL and longer was also calculated (CPUE = 0.93, *SE* = 0.05). This compares to estimates of 1.11 (*SE* unknown), 2.04 (*SE* = 0.23), and 1.16

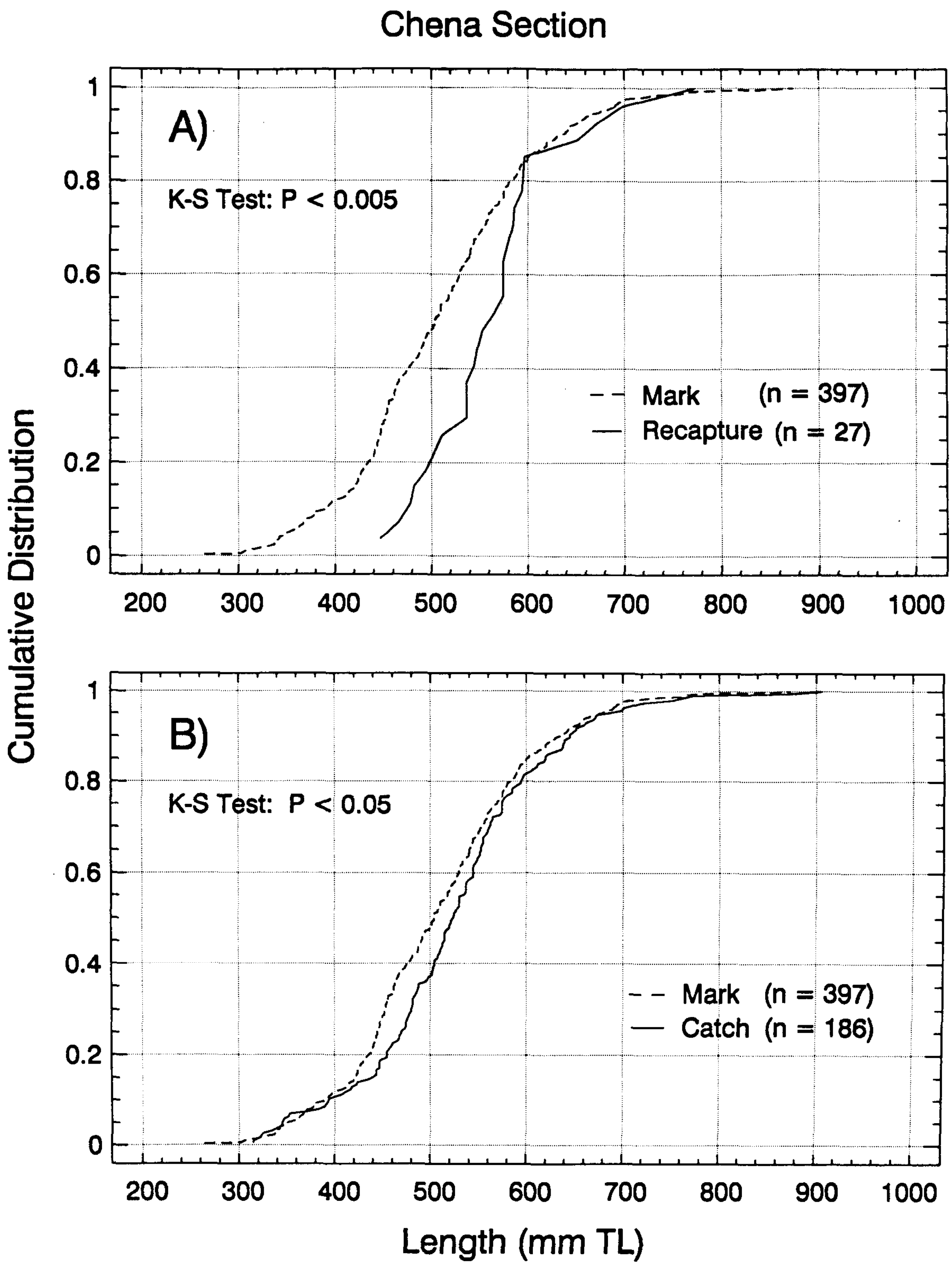

Figure 6. Cumulative length frequency distributions of burbot captured in the Chena section of the lower Chena River, comparing lengths of all burbot captured during the marking sample to: A) lengths of all recaptured burbot; and, B) lengths of all burbot captured during the recapture sample.

Table 5. Results of contingency table analyses of the recapture rates, by length, for burbot captured in the Chena section of the lower Chena River in 1990.

Test	Test Breaks[a] (mm TL) 300	350	400	450	500	550	600	650	700	750	800	Significance Tests[b]
1.	<-----	-----	-----	><	-----	-----	-----	><	-----	-----	-----	$0.025<P<0.05$
2.				<-----	-----	-----	-----	><	-----	-----	-----	$0.90<P<0.95$
3.		<-----	-----	><	-----	-----	-----	-----	-----	-----	-----	$0.01<P<0.025$
4.			<-----	><	-----	-----	-----	-----	-----	-----	-----	$0.05<P<0.10$

[a] Each group of lines corresponds to a battery of tests. The symbols "><" correspond to boundaries between adjacent categories in a test.

[b] Tests are RxC contingency tables and χ^2 statistics for H_o: $p_i = p$ where p_i = probability of catching a burbot in the ith length group. The numbers of marked fish caught and not caught were used in the contingency table.

Table 6. Number of marked burbot (400 mm TL and larger) that were recovered by division in the Chena section of the lower Chena River during 1990.

	River Division			
	Lower	Middle	Upper	Total
Recovered	9	9	8	26
Not Recovered	93	70	144	307
Total Marked	102	79	152	333
Recovery Rate	9%	11%	5%	8%

Table 7. Inter-division movements of recaptured burbot in the Chena section of the lower Chena River during 1990.

Division Tagged	Division Recaptured		
	Lower	Middle	Upper
Lower	8	2	0
Middle	1	7	0
Upper	0	0	7

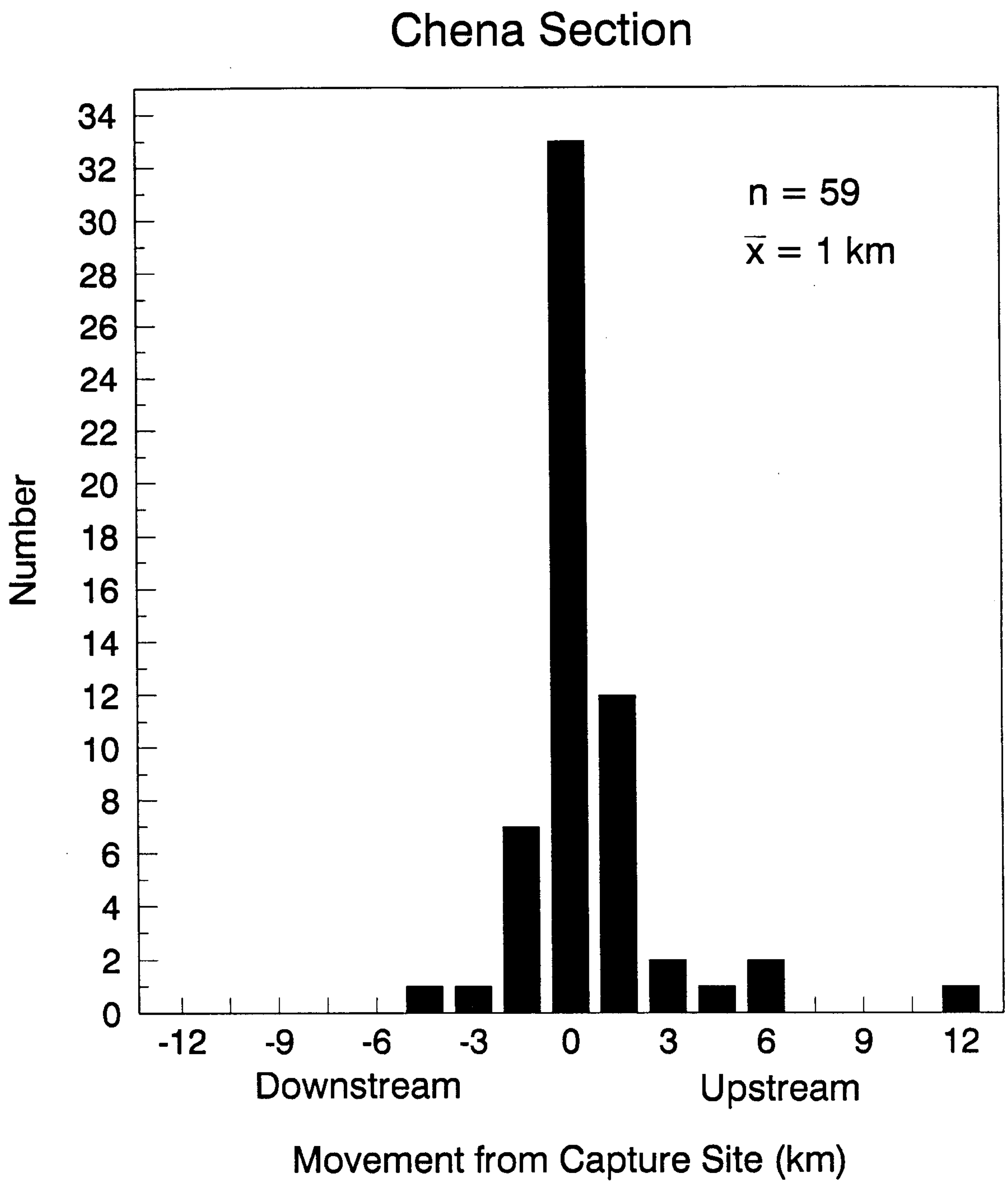

Figure 7. Movements of all recaptured burbot caught during the mark-recapture experiment in the Chena section of the lower Chena River during 1990.

Table 8. Abundance estimate of large burbot (400 mm TL and larger) in the Chena section of the lower Chena River during 1990.

Parameter	Calculated or Known Quantity	Bootstrap Estimate
M_1	102	102
M_2	79	79
M_3	152	152
C	167	167
$R_{..}$	26	26
R_{12}	2	2
R_{23}	0	0
R_2	8	8
R_{21}	1	1
R_{32}	0	0
Θ_u	0.11	0.13
SE	Unknown	0.11
Θ_d	0.04	0.05
SE	Unknown	0.04
$\hat{N}$ (Evenson 1988)	1,966	1,964
SE	Unknown	338
$\hat{N}$ (Bailey 1951,1952)	2,072	
SE	359	

(*SE* = 0.13) for similar sample sections in 1986, 1987, and 1989 respectively (Appendix A1). CPUE was also estimated for large burbot (450 mm and longer) from the first sample and for small burbot (less than 450 mm TL) from both samples. However due to the size selectivity observed in the first event, these estimates were considered biased (Table 9).

Chena Section:

Estimates from the four sampling events conducted during the abundance estimate were pooled to improve precision. A nearly unbiased estimate of mean CPUE was estimated to be 0.93 (*SE* = 0.02) for all burbot 400 mm TL and larger. To be consistent with previous year's data, CPUE was also estimated for all burbot 450 mm TL and larger. Mean CPUE was estimated to be 0.79 (*SE* = 0.03; Table 9) for this length category. This compares to estimates of 0.90 (*SE* = 0.13) and 0.61 (*SE* = 0.09) for similar sample sections in 1988 and 1989 respectively (Appendix A1).

The five estimates of CPUE for large burbot (450 mm TL and larger) ranged from 0.07 (*SE* = 0.02) in the first sampling event conducted in early June (not used for abundance estimate), to 1.21 (*SE* = 0.09) in the fourth sampling event conducted in mid September (Table 9). The five estimates of mean CPUE for small burbot (less than 450 mm TL) ranged from 0.06 (*SE* = 0.02) to 0.33 (*SE* = 0.03) during the same two sampling events respectively.

Fairbanks Section:

Mean CPUE was estimated for three length strata (300 to 449; 450 to 799; and, 800 mm TL and larger). However, because so few burbot were caught in the large length category (3% of total catch), the second and third categories were pooled and a single, nearly unbiased estimate of mean CPUE for all burbot 450 mm TL and larger was calculated. Mean CPUE was estimated to be 1.11 (*SE* = 0.12; Table 9). This compares to estimates of 0.77 (SE unknown), 0.81 (*SE* = 0.05), 0.53 (*SE* = 0.05), and 0.55 (*SE* = 0.05) for similar sample sections in 1986 through 1989, respectively (Appendix A1).

Relationship of CPUE to Actual Abundance:

To date, five estimates of abundance and associated estimates of mean CPUE have been obtained for four different river sections located throughout the Tanana River drainage. The relationship does not seem to be linear, as catchability coefficients are shown to range from 0.005 to 0.012 (Table 10).

Length Composition

Mean lengths were calculated for three strata (300 to 449, 450 to 799, and 800 mm TL and larger). Convention in the past has been to estimate mean length of all burbot 450 mm TL and longer. Therefore, for comparative purposes, the second and third strata were pooled and an additional estimate of mean length was calculated (Table 11). In all but the Fairbanks section, these estimates are considered unbiased.

Table 9. Catch-per-unit of effort for large and small burbot sampled in sections of the Chena and Tanana rivers during 1990.

Event	Sampling Dates	Net-Nights	Large Burbot[a]			Small Burbot[a]		
			Catch	CPUE[b]	SE	Catch	CPUE[b]	SE
			Chena Section					
1	6/12 - 6/15	232	16	0.07	0.02	14	0.06	0.02
2	8/21 - 8/24	204	84	0.41	0.06	42	0.21	0.04
3	8/27 - 8/31	203	206	1.01	0.11	60	0.30	0.04
4	9/6 - 9/7	73	88	1.21	0.09	24	0.33	0.03
5	9/27 - 9/28	80	66	0.83	0.05	11	0.14	0.03
2-5	8/21 - 9/28	560	445	0.79[c]	0.03	137	0.24	0.02
			Northway Section					
1	6/21 - 6/28	458	268	0.59	0.04	109	0.24	0.03
2	7/10 - 7/18	393	364	0.93[c]	0.05	89	0.23	0.02
			Fairbanks Section					
1	8/14 - 8/16	90	100	1.11[c]	0.12	44	0.49	0.10

[a] Large burbot are 450 mm total length and larger, and small burbot are less than 450 mm total length.
[b] Catch-per-unit of effort is defined as burbot per net-night.
[c] Represents the least biased estimate for each section.

Table 10. Comparison of density and catch-per-unit-effort estimates for five river sections in the Tanana River drainage.

River	Locality	River km Sampled[a]	Year	Density[b]	SE	CPUE[c]	SE	Catchability Coefficient[d]
Tanana	Fairbanks	336 - 352	1986	121	28	0.82	ND[e]	0.007
Tanana	Fairbanks	336 - 352	1987	159	43	0.86	0.10	0.005
Tanana	Healy Lake	582 - 589	1987	572	41	7.02	0.86	0.012
Tanana	Northway	888 - 912	1990	93	19	0.93	0.05	0.010
Chena	Fairbanks	0 - 24	1990	73	11	0.79	0.03	0.011

[a] River kilometers are measured upstream from the river mouth.
[b] Density estimates are shown as number of large burbot (450 mm TL and larger) per river kilometer.
[c] Catch-per-unit-effort estimates (CPUE) are shown as number of large burbot per net-night.
[d] Calculated as CPUE divided by abundance (from Everhart and Youngs 1981).
[e] No data.

Table 11. Mean length estimates of burbot sampled in sections of the Chena and Tanana rivers during 1990.

Sampling Event	Length Range (mm TL)	<450 mm TL			450 - 800 mm TL			>800 mm TL			All >450 mm TL		
		n	mean	SE	n	mean	SE	n	mean	SE	n	mean	SE
					Chena River								
6/12 - 6/15	265 - 600	14	375	14	16	510	12	0	ND	ND	16	510	12
8/20 - 8/23	302 - 873	41	400	7	82	540	8	1	873	ND	83	544	8
8/28 - 8/31	294 - 852	59	409	5	204	555	5	1	852	ND	205	556	5
9/06 - 9/07	316 - 762	26	391	9	90	554	7	0	ND	ND	90	554	7
9/27 - 9/28	315 - 905	9	381	18	66	554	9	2	888	18	68	564	9
2-5	265 - 905	135	401	1	441[a]	551	3	4	875[a]	11	445	552[a]	4
					Tanana River at Northway								
6/21 - 6/28	246 - 986	109	389	4	254	564	5	14	846	15	268	579	5
7/10 - 7/18	270 - 1,030	89	396	4	331	590[a]	5	33	884[a]	12	364	617[a]	5
ALL	246 - 1,030	198	389	3	585	578	4	47	872	10	632	597	4
					Tanana River at Fairbanks								
8/14 - 8/16	300 - 900	44	393	6	96	540[a]	8	4	856	23	100	553	8

[a] Represents a nearly unbiased estimate of the true mean.

In the Northway section, length data from the second sampling event was used to calculate an unbiased estimate for burbot 450 mm and longer (mean = 617; *SE* = 5 mm TL). This compares to estimates of 633 (*SE* = 7), 596 (*SE* = 9), and 641 (*SE* = 11) for similar sample sections in 1986, 1987, and 1989, respectively (Appendix A2).

In the Chena section, length data from the last four sampling events (all events used to estimate abundance) was used to calculate an unbiased estimate of mean length (mean = 552; *SE* = 4 mm TL). This compares to estimates of 557 (*SE* = 8) and 571 (*SE* = 10) for similar sample sections in 1988 and 1989 respectively (Appendix A2). Mean lengths from the five sampling events ranged from 510 (*SE* = 12) to 564 (*SE* = 9) mm TL in the first and last events, respectively.

Mean length of all burbot 450 m TL and longer in the Fairbanks section was 553 (*SE* = 8). This compares to estimates of 574 (*SE* = 5), 583 (*SE* = 6), 523 (*SE* = 6), and 549 (*SE* = 8) for similar sample sections in 1986 through 1989 respectively (Appendix A2).

Proportions of Relative Stock Densities indicated that nearly 80% of all burbot sampled in the Chena and Fairbanks sections were of quality size (450 to 599 mm TL. This proportion was much lower in the Northway section in which 56% were of quality size. In the Chena and Northway sections there was a general increase in size compositions with successive sampling events (Table 12; Appendix A3).

DISCUSSION

One of the goals of this long-term stock assessment program is to discern sustainable yield of the population. Previous analysis of migratory behavior has indicated that adult burbot mix throughout the mainstem Tanana River and its tributaries (Evenson 1989), and suggests that this population should be considered a single stock. Hence, to determine sustainable yield, an estimate of abundance is required for the entire system.

Attainment of this goal is complicated by several factors. First, due to the immenseness of this river system, only a small portion can be reasonably sampled in a single season. Second, there is considerable variability in size and density distributions among river sections. These two conditions require that estimates of abundance be obtained for many river sections, and that these estimates need be conducted over the course of several years. The necessary assumption of this design is that the population remains stable over the span of the study. That is, fishing mortality is negligible compared to population abundance.

Current harvests average between 3,500 and 4,000 burbot annually (Mills 1988-1990). A rough approximation of abundance based on observed densities (from five estimates of abundance; see Table 10) is somewhere between 100,000 and 200,000 burbot (mean density times 1,000 river kilometers). While a harvest of 3,000 to 4,000 burbot may not be negligible, it is a very small source of bias.

Table 12. Relative Stock Density estimates of burbot captured in sections of the Chena and Tanana rivers during 1990.

			Category / Gabelhouse Minimum Length[a] (mm TL)			
Event	Sampling Dates		Quality 450	Preferred 600	Memorable 700	Trophy 800
			Chena Section			
1	6/12 - 6/15	RSD[b]	0.94	0.06	0.00	0.00
		SE[RSD]	0.06	0.04	0.00	0.00
2	8/20 - 8/23	RSD	0.83	0.13	0.02	0.01
		SE[RSD]	0.04	0.04	0.02	0.01
3	8/28 - 8/31	RSD	0.76	0.20	0.03	<0.01
		SE[RSD]	0.03	0.03	0.01	<0.01
4	9/06 - 9/07	RSD	0.79	0.17	0.04	0.00
		SE[RSD]	0.04	0.04	0.02	0.00
5	9/27 - 9/28	RSD	0.74	0.19	0.04	0.03
		SE[RSD]	0.05	0.05	0.02	0.02
2-5	8/20 - 9/28	RSD	0.78	0.18	0.04	<0.01
		SE[RSD]	0.02	0.02	0.01	<0.01
			Northway Section			
1	6/21 - 6/28	RSD	0.68	0.18	0.09	0.05
		SE[RSD]	0.03	0.02	0.02	0.01
2	7/10 - 7/18	RSD	0.56	0.21	0.14	0.09
		SE[RSD]	0.03	0.02	0.02	0.02
			Fairbanks Section			
1	8/14 - 8/16	RSD	0.80	0.09	0.07	0.04
		SE[RSD]	0.04	0.03	0.03	0.02

[a] Minimum lengths for each category derived from Gabelhouse (1984).
[b] Relative Stock Density expressed as a percentage.

An important artifact of this sampling design will be the development of a stock assessment program based solely on abundance indexing. Since 1986, this research program has generated nearly 50 indices of abundance (based on CPUE) and size composition estimates for various river sections throughout the Tanana River and its tributaries (Hallberg et al. 1987; Evenson 1988-1990 and this study). However, only five estimates of abundance have been derived during the same time frame. As more estimates of abundance are obtained in future sampling, the relationship between CPUE and actual abundance will become more defined, such that abundance can be determined entirely from CPUE estimates. This will enable estimation of abundance for more river sections during one summer sampling period. Additionally, estimating system-wide parameters such as survival and recruitment may be possible with this type of sampling design.

The estimates of abundance for the Chena and Northway sections obtained in this study did not meet the objective criteria for accuracy (±25% of the true value 95% of the time). Relative precision of these estimates were 34% and 37% respectively. In both cases this shortfall in accuracy was due to an underestimate of expected abundance when calculating sample sizes. In future studies, a more conservative approach needs to be taken when estimating abundance for determining sample size. As the relationship between CPUE and actual abundance becomes more clear, expected abundance can be better estimated for many river sections based on historic CPUE data.

The five sampling events conducted in the Chena River showed that CPUE and mean length estimates differed vastly between June and September (Tables 9 and 11). The movement behavior of recaptured fish (from all five sampling events) did not indicate that there was significant movement into or out of the study area over the span of the sampling events (Figure 7). This information indicates that the observed differences in CPUE and mean length estimates can be attributed to changes in catchability rather than changes in actual abundance. If a relationship between CPUE and actual abundance is to be developed, these seasonal variations in catchability need to be considered.

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APPENDIX A

Appendix A1. Summary of catch-per-unit of effort (CPUE) estimates for burbot sampled in three sections of the Tanana River drainage, 1986-1990

Year	Sampling Dates	River km Sampled	Net-Nights	Catch[a]			CPUE[b]					
				Large	Small	All	Large	SE	Small	SE	All[d]	SE
				Northway Section								
1986	9/16 - 9/20	889-912	458	508	84	592	1.11	ND[c]	0.18	ND	1.29	ND
1987	7/14 - 7/17	894-915	93	190	45	235	2.04	0.23	0.48	0.10	2.53	0.19
1989	8/27 - 8/29	908-946	122	142	15	157	1.16	0.13	0.12	0.04	1.29	0.12
1990	7/10 - 7/18	894-928	393	364	89	453	0.93	0.05	0.23	0.02	1.15	0.04
				Chena Section								
1988	9/6 - 9/9	0-24	88	65	23	88	0.90	0.13	0.32	0.08	1.00	0.10
1989	6/27 - 6/30	0-40	120	73	30	103	0.61	0.09	0.25	0.06	0.86	0.07
1990	8/20 - 9/28	0-24	560	444	127	581	0.79	0.03	0.24	0.02	1.04	0.02
				Fairbanks Section								
1986	7/29 - 8/15	334-377	466	287	143	430	0.62	ND	0.31	ND	0.92	ND
1987	7/22 - 8/20	339-378	525	425	217	642	0.81	0.05	0.41	0.04	1.22	0.03
1988	7/6 - 7/9	312-376	268	143	159	302	0.53	0.05	0.59	0.05	1.12	0.07
1989	6/13 - 6/16	317-374	237	131	137	268	0.55	0.05	0.58	0.06	1.13	0.04
1990	8/14 - 8/16	344-376	90	100	44	144	1.11	0.12	0.49	0.10	1.60	0.09

[a] Large burbot are 450 mm total length and larger, and small burbot are less than 450 mm total length.
[b] Catch-per-unit of effort is defined as burbot per net-night.
[c] No data.
[d] Includes all burbot greater than 300 mm TL.

Appendix A2. Summary of mean length estimates for burbot sampled in three sections of the Tanana River drainage, 1986-1990.

Year	Sampling Dates	River km Sampled	Length Range (mm TL)	Catch[a]			Mean Length (mm TL)					
				Large	Small	All	Large	SE	Small	SE	All	SE
					Northway Section							
1986	9/16 - 9/20	889-912	270 - 1,147	508	84	592	633	7	383	5	598	6
1987	7/14 - 7/17	894-915	307 - 1,010	190	45	235	596	9	392	6	557	7
1989	8/27 - 8/29	908-946	347 - 1,060	142	15	157	641	11	412	9	619	10
1990	7/10 - 7/18	894-928	270 - 1,030	364	89	453	617	5	397	4	574	4
					Chena Section							
1988	9/6 - 9/9	0-24	306 - 754	65	23	88	557	8	394	8	514	6
1989	6/27 - 6/30	0-40	295 - 802	73	30	103	571	10	366	6	511	7
1990	8/20 - 9/28	0-24	265 - 905	444	127	581	552	4	401	4	509	3
					Fairbanks Section							
1986	7/29 - 8/15	334-377	258 - 922	361	180	541	574	5	385	3	511	3
1987	7/22 - 8/20	339-378	304 - 1,079	425	217	642	583	6	398	2	520	4
1988	7/6 - 7/9	312-376	235 - 855	143	159	302	523	6	388	3	452	3
1989	6/13 - 6/16	317-374	278 - 895	131	137	268	549	8	381	4	463	4
1990	8/14 - 8/16	344-376	300 - 900	100	44	144	553	8	393	6	504	6

[a] Large burbot are 450 mm total length and larger, and small burbot are less than 450 mm total length.

Appendix A3. Summary of Relative Stock Density estimates for burbot sampled in three sections of the Tanana River drainage, 1986-1990.

Year	Sampling Dates	River km Sampled	Sample Size		Category / Gabelhouse Minimum Length[a] (mm TL) Quality 450	Preferred 600	Memorable 700	Trophy 800
Northway Section								
1986	9/16 - 9/20	889 - 912	508	RSD[b]	0.55	0.17	0.12	0.16
				SE[RSD]	0.02	0.02	0.01	0.02
1987	7/14 - 7/17	894 - 915	190	RSD	0.66	0.14	0.12	0.09
				SE[RSD]	0.03	0.02	0.02	0.02
1989	8/27 - 8/29	908 - 946	142	RSD	0.36	0.33	0.20	0.11
				SE[RSD]	0.04	0.04	0.03	0.03
1990	7/10 - 7/18	894 - 928	364	RSD	0.56	0.21	0.14	0.09
				SE[RSD]	0.03	0.02	0.02	0.02
Chena Section								
1988	9/6 - 9/9	0 - 24	65	RSD	0.78	0.17	0.05	0
				SE[RSD]	0.05	0.05	0.03	0
1989	6/27 - 6/30	0 - 40	73	RSD	0.68	0.21	0.09	0.01
				SE[RSD]	0.05	0.05	0.03	0.01
1990	8/20 - 9/28	0 - 24	444	RSD	0.78	0.18	0.04	<0.01
				SE[RSD]	0.02	0.02	0.01	<0.01
Fairbanks Section								
1986	7/29 - 8/15	334 - 377	287	RSD	0.70	0.16	0.08	0.06
				SE[RSD]	0.03	0.02	0.02	0.01
1987	7/22 - 8/20	339 - 378	425	RSD	0.67	0.15	0.10	0.08
				SE[RSD]	0.02	0.02	0.02	0.01
1988	7/6 - 7/9	312 - 376	143	RSD	0.90	0.07	0.02	0.01
				SE[RSD]	0.02	0.02	0.01	0.01
1989	6/13 - 6/16	317 - 374	131	RSD	0.79	0.15	0.02	0.05
				SE[RSD]	0.04	0.03	0.01	0.02
1990	8/14 - 8/16	344 - 376	100	RSD	0.80	0.09	0.07	0.04
				SE[RSD]	0.04	0.03	0.03	0.02

[a] Minimum lengths for each category derived from Gabelhouse (1984).
[b] Relative Stock Density expressed as a percentage.

APPENDIX B

Appendix B1. Statistical tests used to analyze mark-recapture data for significant bias due to gear selectivity by length.

Test A. Kolmogorov-Smirnov two sample test comparing the distributions of the lengths of all fish that were marked during the marking sample and all marked fish that were collected during the recapture sample; and,

Test B. Kolmogorov-Smirnov two sample test comparing the distributions of the lengths of all fish that were captured during the marking sample and all fish that were collected during the recapture sample.

The null hypothesis is no difference between the distributions of lengths for Test A or for Test B.

For these two tests there are four possible outcomes:

Case I:

Accept $H_o(A)$ Accept $H_o(B)$

There is no size-selectivity during the first sample (when burbot were marked) or during the second sample (when burbot were collected).

Case II:

Accept $H_o(A)$ Reject $H_o(B)$

There is no size-selectivity during the second sample but there is size-selectivity during the first sample.

Case III:

Reject $H_o(A)$ Accept $H_o(B)$

There is size-selectivity during both samples.

Case IV:

Reject $H_o(A)$ Reject $H_o(B)$

There is size-selectivity during the second sample; the status of size-selectivity during the first sample is unknown.

-continued-

Depending on the outcome of the tests, the following procedures will be used to estimate the abundance of the population:

Case I: Calculate one unstratified estimate of abundance, and pool lengths from both samples to improve precision of proportions in estimates of compositions.

Case II: Calculate one unstratified estimate of abundance, and only use lengths from the second sample to estimate proportions in compositions.

Case III: Completely stratify both samples, and estimate the abundance for each stratum. Add the estimates of abundance across strata to get a single estimate for the population. Pool lengths from both samples to improve precision of proportions in estimates of composition, and apply formulae to correct for size bias to the pooled data.

Case IV: Completely stratify both samples and estimate the abundance for each stratum. Add the estimates of abundance across strata to get a single estimate for the population. Also, calculate a single estimate of abundance without stratification.

Case IVa: If the stratified and unstratified estimates of abundance for the entire population are dissimilar, discard the unstratified estimate. Only use the lengths the second sample to estimate proportions in composition, and apply formulae to correct for size bias to data from the second sample.

Case IVb: If the stratified and unstratified estimates of abundance for the entire population are similar, discard the estimate with the larger variance. Only use the lengths from the first sample to estimate proportions in compositions, and do not apply formulae to correct for size bias.

To determine the appropriate breaks for length strata, a battery of R X C contingency table analyses were performed. Each table consisted of two rows corresponding to the number of recaptured and not recaptured fish. The number of columns varied between tests, and were comprised of two or more length categories.